National Aeronautics and Space Administration

Integrated Approach to Architecting, Modeling, and Simulation of Complex Space Communication Networks

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SPACE COMMUNICATIONS AND NAVIGATION

Keeping the universe connected.

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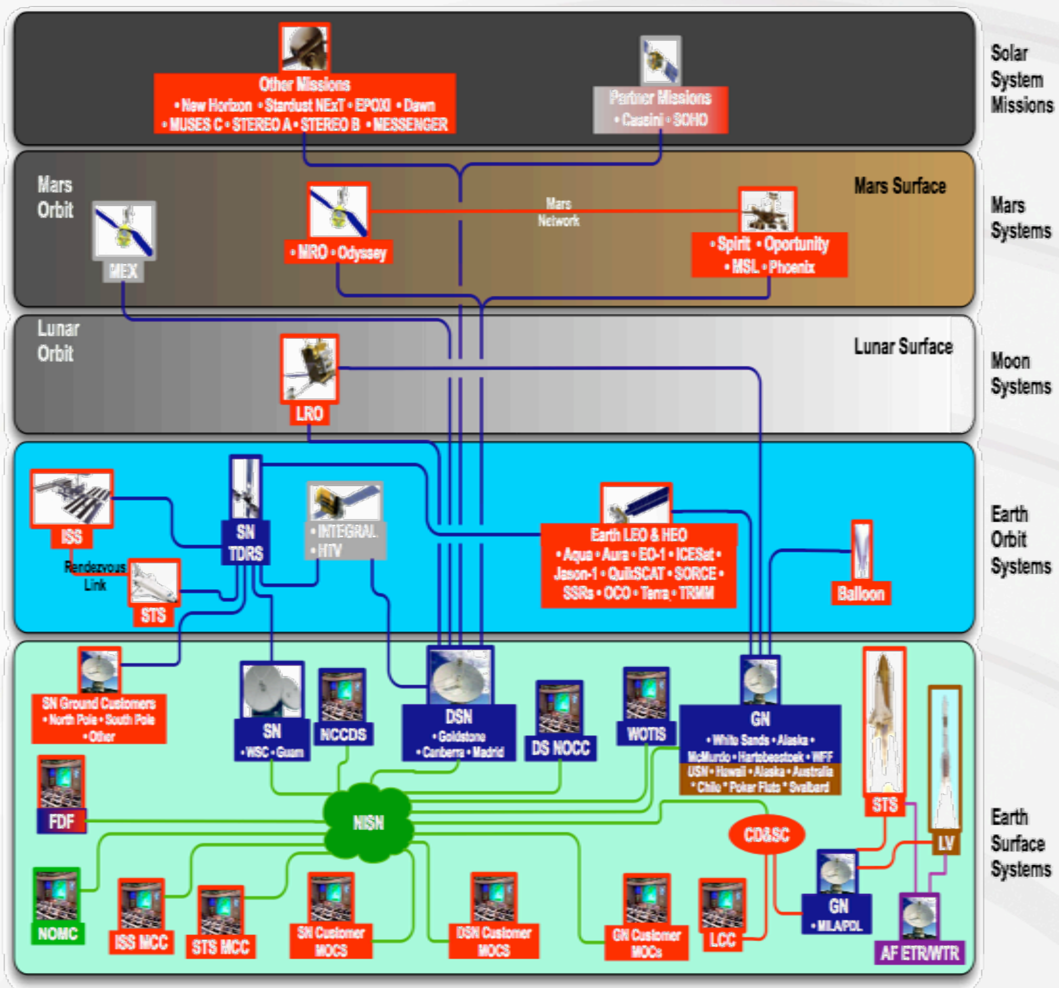
Outline

- Integration Drivers
- Communication Systems & Network Architecting
  - Architecture Decomposition
  - Defining Systems and Interfaces
- Architecture Modeling
  - Architecture Frameworks & MBSE
  - Architecture Simulation
- End-to-End Simulation
  - GEMINI – Glenn's Environment for Modeling Integrated Network Infrastructure
- Integrated Architecture Modeling & Simulation
  - MBSE Extension of GEMINI Tool
- Conclusion

Increasing Complexity in Mission Network Infrastructure

- Space communication networks servicing multiple coordinated space assets must work together in systems of systems
- Service providers are integrating and expanding their infrastructure to become a network-of-networks
- The infusion of higher layer services results in a multi-layered network architecture
- Additional relay capabilities
- Expanding mission interface and performance requirements

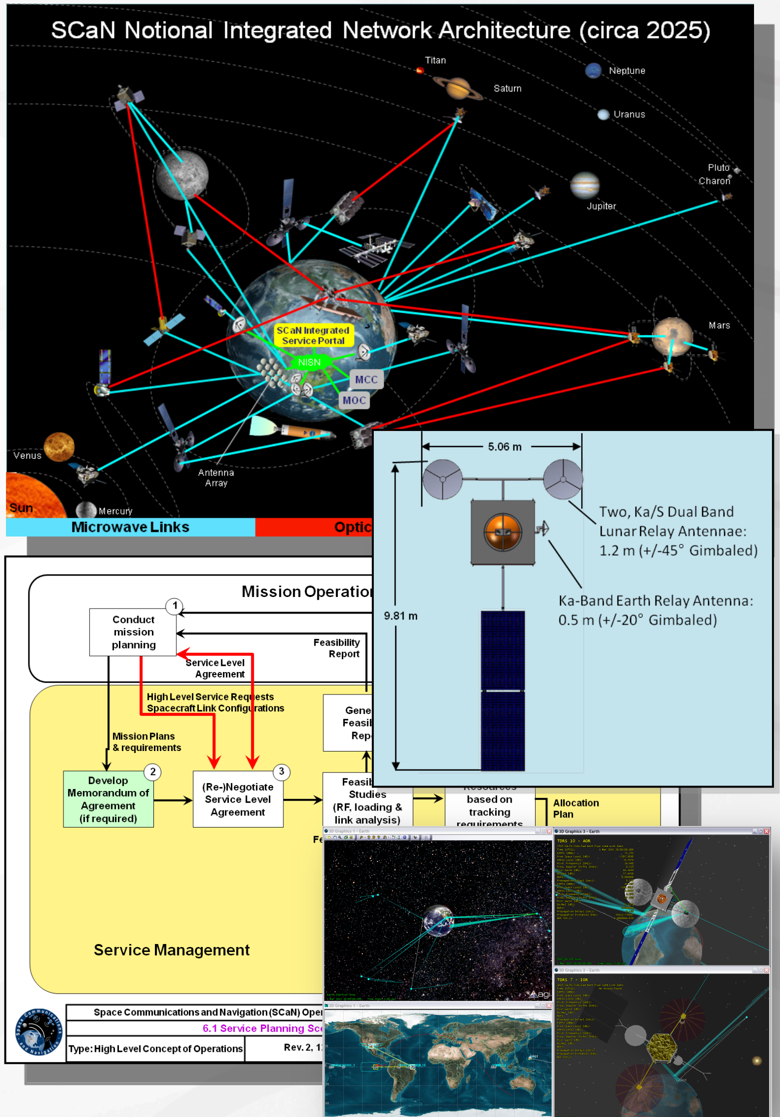


Need for Integration of Architecture, Modeling, and Simulation

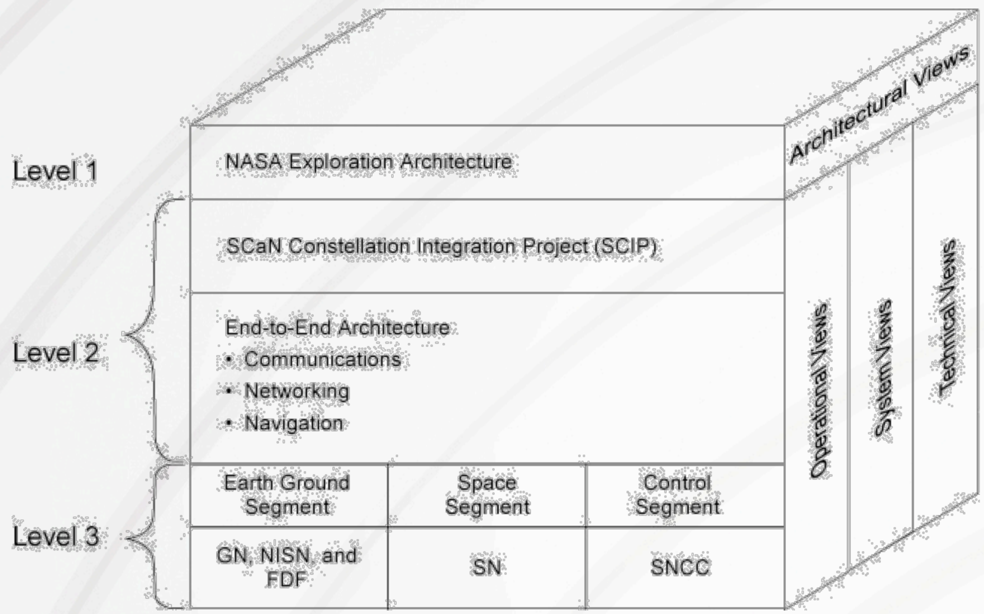
- Manage complexity through SE practices:
  - Systems Architecting
  - Architecture Modeling
  - Network Simulation

- Over the past several years, our team has applied these techniques to address increasing complexities.

- *Now, we are integrating the processes and tools developed and used in these practices to further reduce cost and risk…*



Architecture Decomposition



- Architecture widens as it moves from high-level organizations to lower-level systems that are each still complex enough to require their own architecture
- Architectures must integrate moving up, down, and across for the system of systems to operate

- Architecture decomposes vertically by level of detail, and levels within organizational hierarchy
- Architecture views offer differing perspectives on the system, including:
  - Operational aspects, processes, dependencies, etc.
  - Physical systems and implementation detail
  - Technical standards and specific technologies for interoperability
- All views must be consistent with one another, though they capture different aspects of the system

Architecture Frameworks & MBSE

Architecture Frameworks

- Architecture frameworks prescribe sets of viewpoints which complex systems can be described using; viewpoints represent the data in ways relevant to particular stakeholders or specific aspects of the system
- The Department of Defense Architecture Framework (DoDAF) and the CCSDS Reference Architecture for Space Data Systems (RASDS) are examples of architecture frameworks that have been successfully applied to the description and definition of space systems

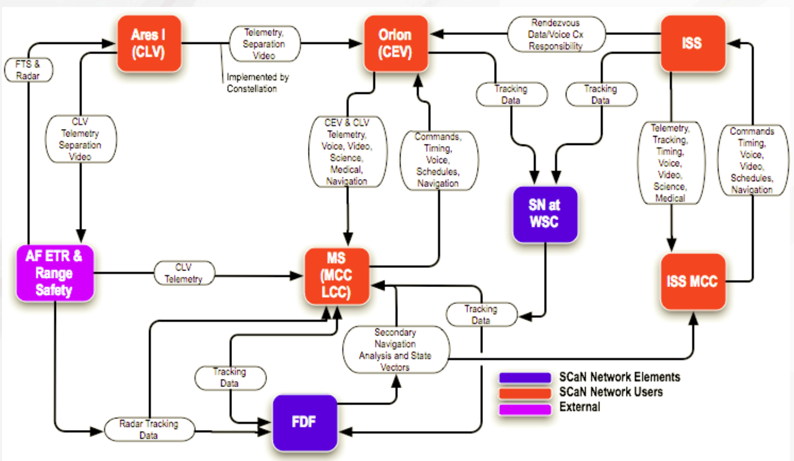
Model-Based Systems Engineering (MBSE)

- MBSE techniques utilize modern software technology and techniques to capture a system's data within a structured database which can be used to maintain consistency between views, automate document generation, and support advanced queries on requirements, interfaces, and other system data being managed
- MBSE schemas corresponding to architecture frameworks allow automation of conforming architecture product generation (diagrams, matrices, reports, etc)

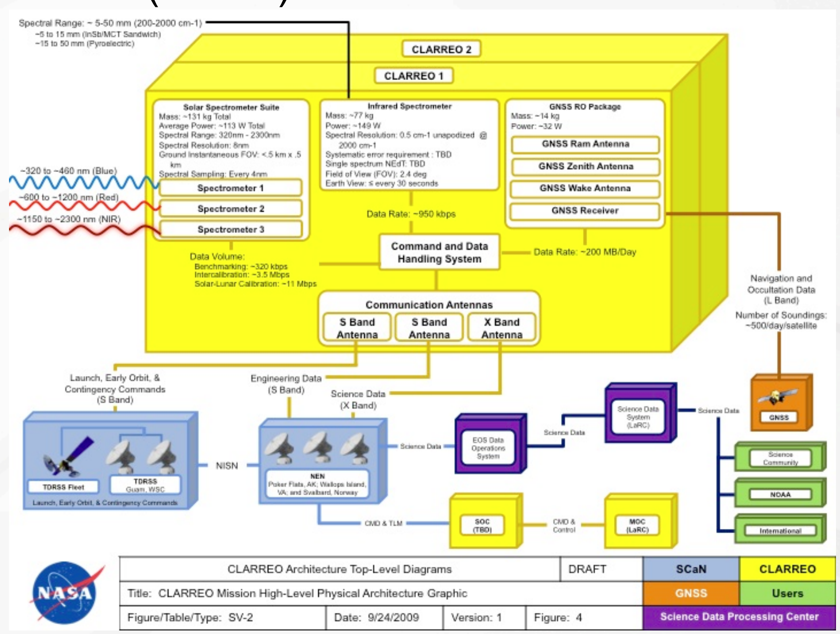
DoDAF Applied to NASA Missions

NASA Glenn has constructed architectures for several projects, applying DoDAF 1.5 and RASDS along with some customization

- SCaN Orion-ISS phase mission architecture for SCaN Constellation Integration Project (SCIP)
- SCaN As-Is Networks Architecture
- SCaN Unified Network Architecture
- Space Network (SN) Ground Segment Sustainment (SGSS)
- Earth Systematic Missions (ESM)



OV-2 diagram showing operational interfaces required for Orion-ISS mission



SV-2 System Communications Description for ESM's CLARREO

Architecture Modeling & Simulation

MBSE Simulation Tools

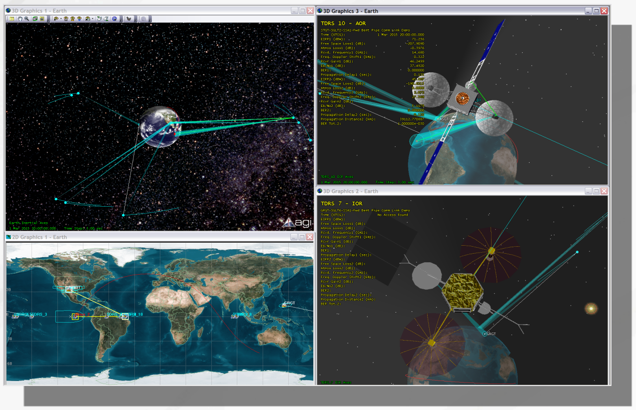
- Some modern MBSE tools, such as ViTech's CORE, also support simulation of discrete-event processes and can report on projected resources, timing, etc.
- Good for modeling high-level processes and sequences of events

Challenges

- **The detailed multi-layered communication and networking protocol operation is not simulated directly within MBSE tools, however MBSE tools can capture the technical configuration information required**
- Space communication system performance is sufficiently complex to require a separate tool focused on propagation, antenna modeling, orbital dynamics, vehicle attitude, atmospheric and environment effects, interference, etc.
- Network protocol behaviors are complex enough to require a separate tool focused on protocol state machines, timers, configuration of nodes, routing algorithms, quality of service mechanisms, etc.
- **But the existing, domain-specific simulation tools are not integrated to support consistent management of technical**

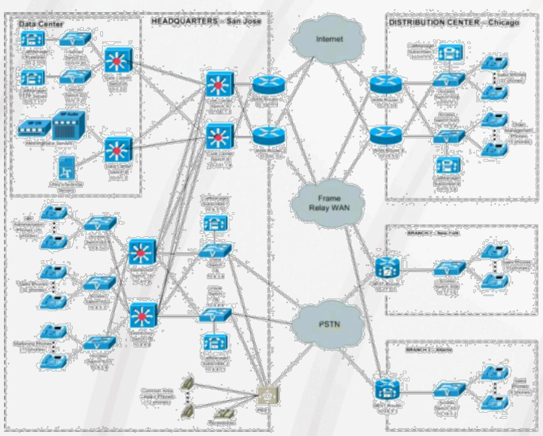
End-to-End Space Networking Simulation

Space Link Models



Problem #1 – Parameters used in space link models, network topology and protocol models, and traffic models need to be managed consistently and rigorously kept up-to-date as system design proceeds; no tools exist for CM across simulators

Network Topology & Protocol Models



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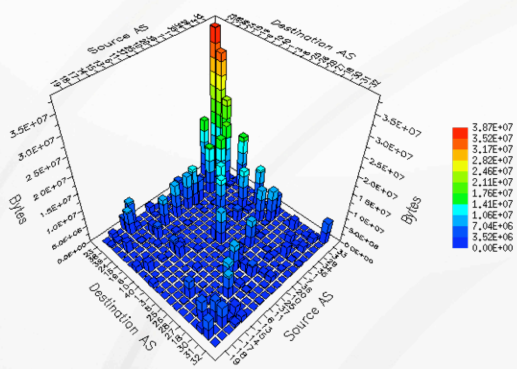
Network Traffic Models



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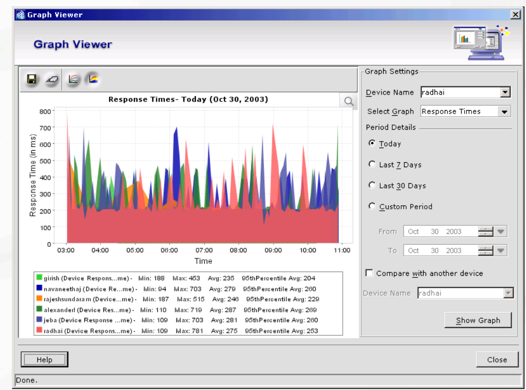
Network Performance



Problem #2 – Detailed performance results need to be tied to specific design configurations and incorporated with architecture decisions through trade studies or other processes

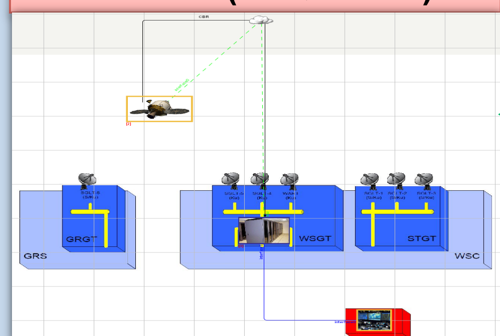
GEMINI – Glenn's Environment for Modeling Integrated Network Infrastructure

- Precisely quantifies network performance at all layers by modeling and dynamically simulating network traffic, protocols, topology, and space links for missions and projects

- Allow the reuse of existing vetted models developed by subject-matter experts across both the network simulation and the astrophysics simulation domains

SCaN Simulator – GEMINI Series

Ground Segment Models (in QualNet)

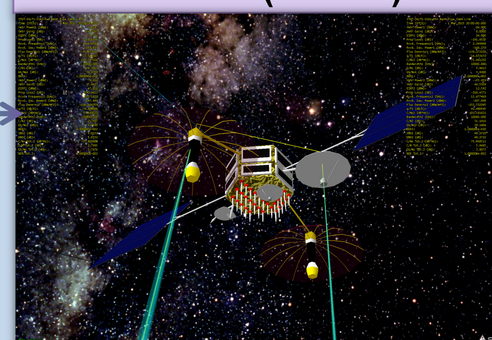


Custom GRC Software for real-time integration of two COTS software tools:

QualNet
(network and protocol simulator)

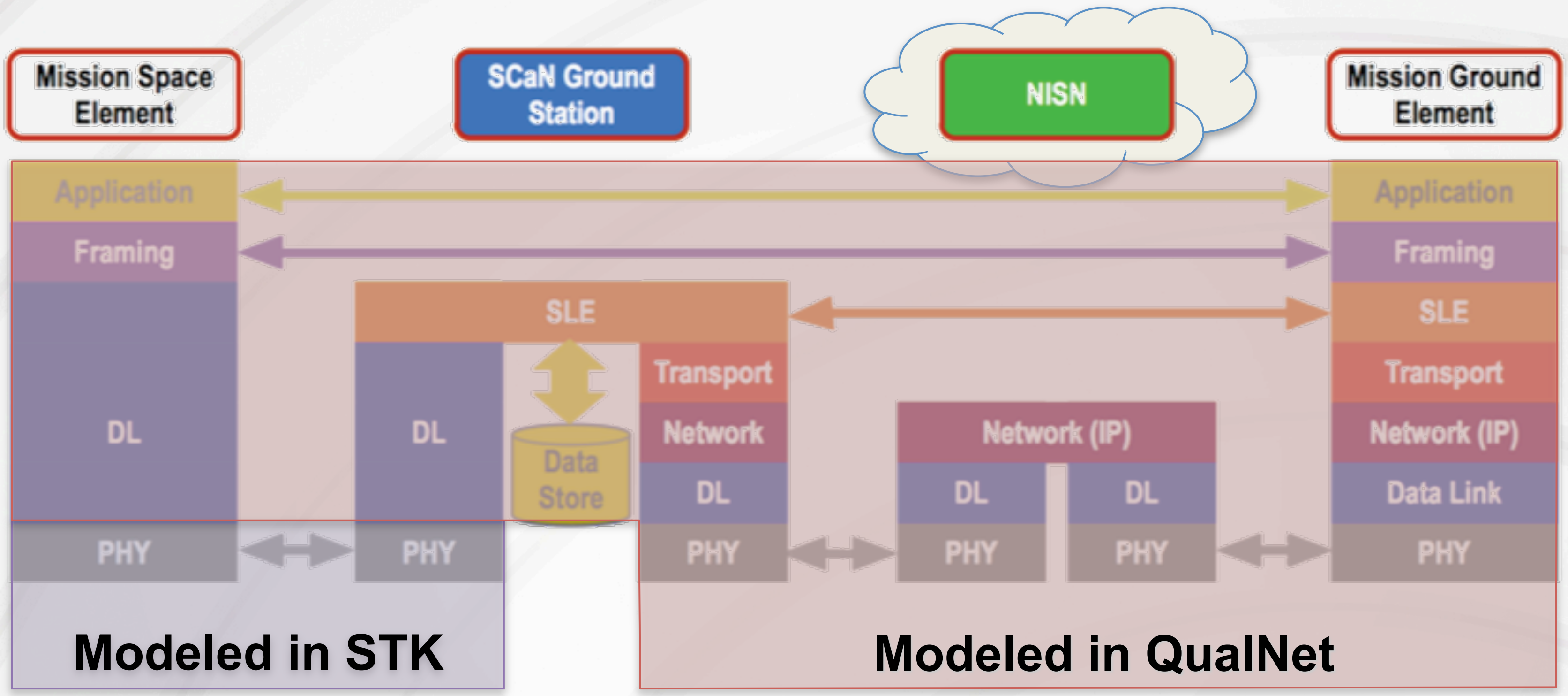
STK
(physics & RF communications system simulator)

Space Segment Models (in STK)



GEMINI = [NASA] Glenn's Environment for Modeling Integrated Network Infrastructure

GEMINI Design Concept



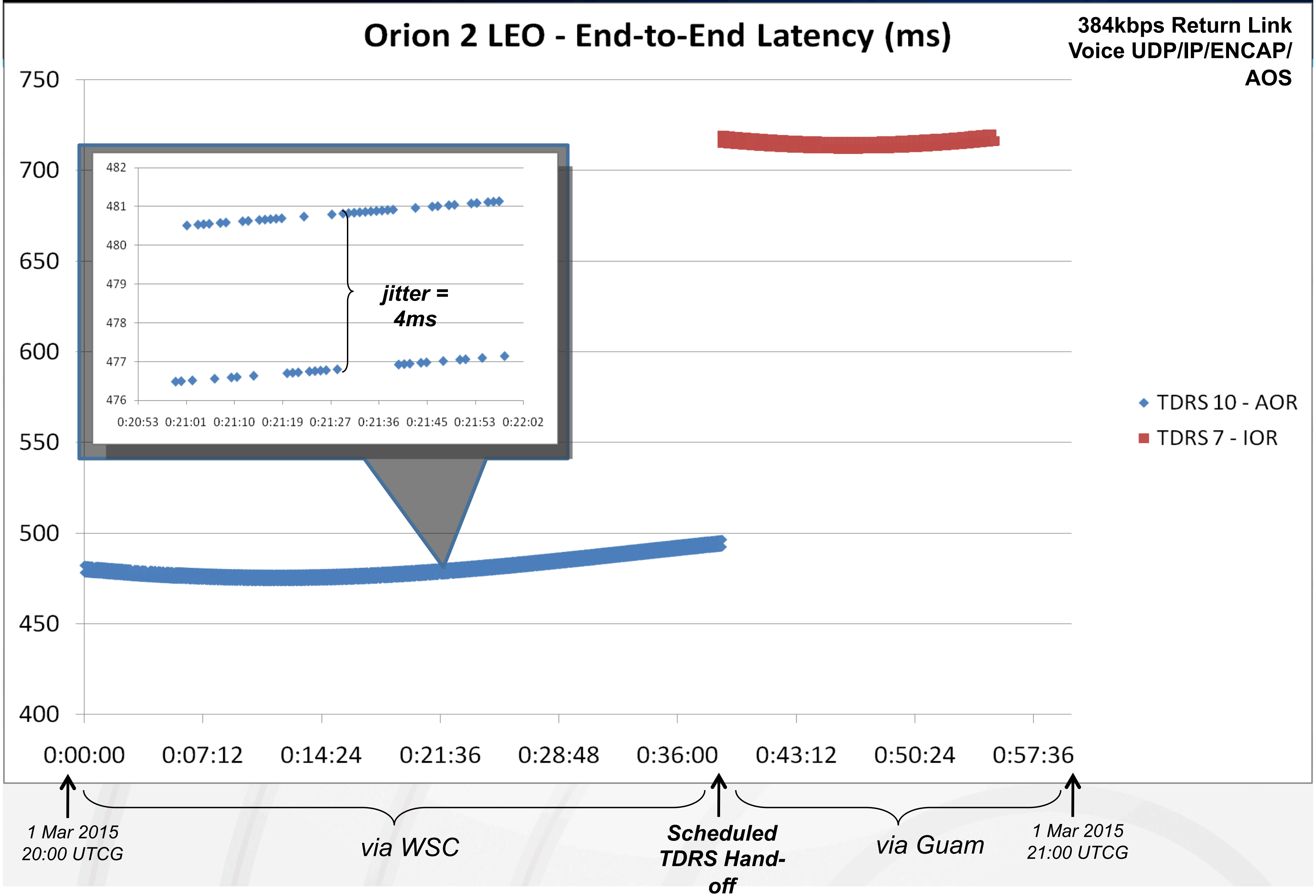
QualNet/STK Integration

- Integration occurs at the simulated physical/data-link layer interfaces
- For simulation of outbound frame radiation across space links, our custom code queries the corresponding model in STK. STK responds with the link data for that interval.

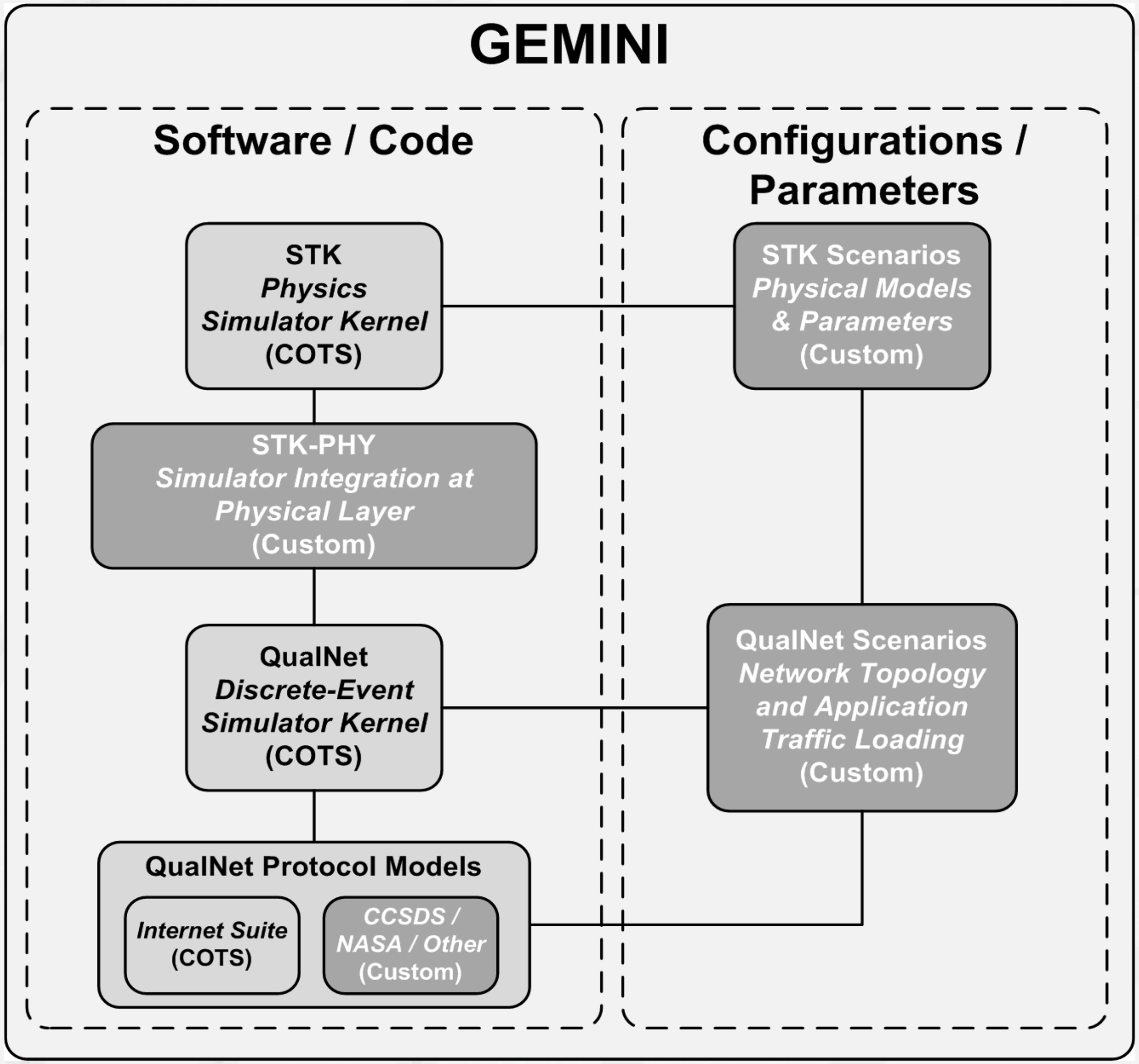
GEMINI Use Case

- Simulated one hour of bi-directional voice traffic between Orion and MCC
- Relayed by TDRSS to ground stations, then flowed through complex Intranet
- Scheduled hand-off between geostationary relay satellites after 40 minutes, diverting traffic flow through a ground station in Guam vs White Sands, NM.

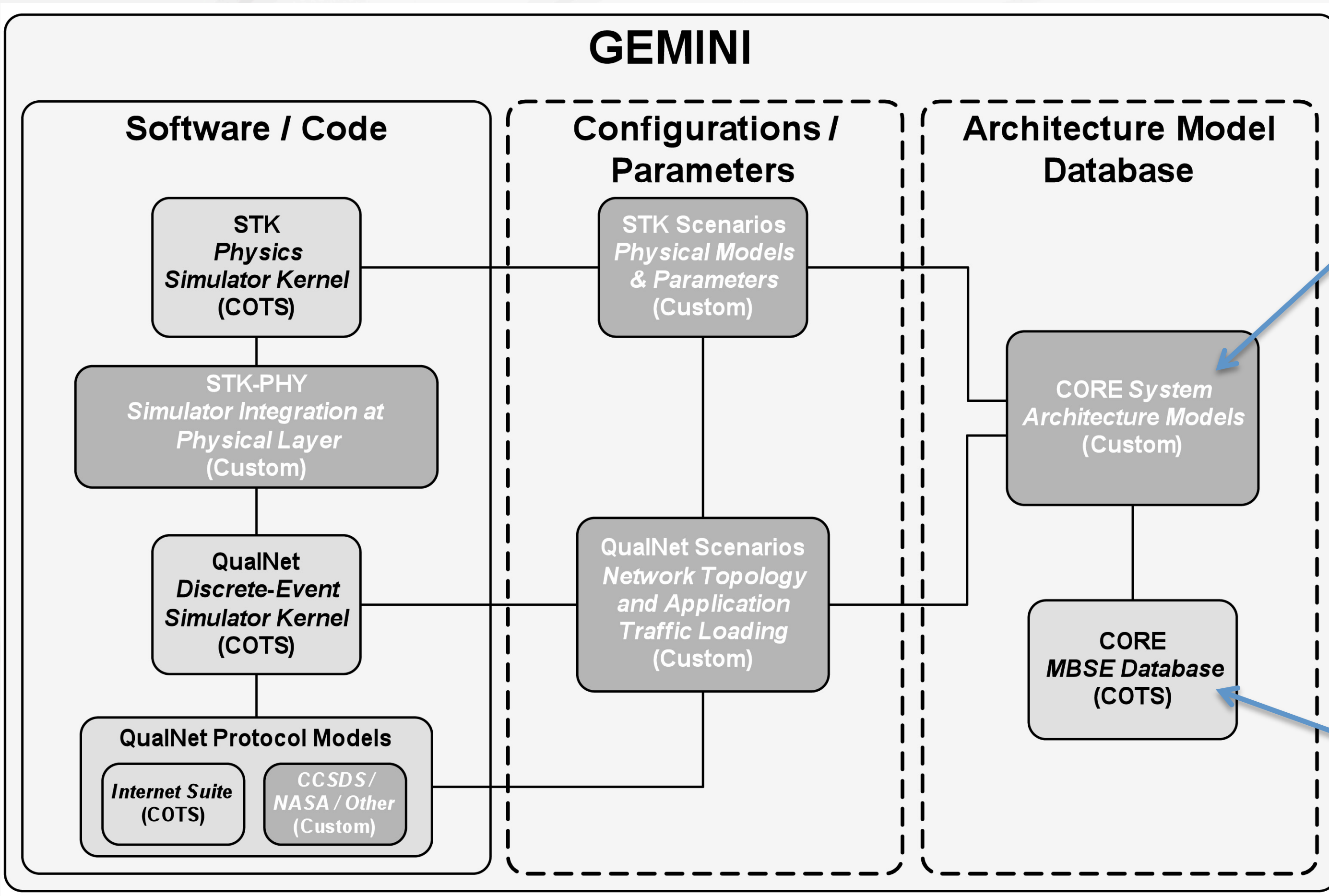
Simulation Results



Current GEMINI Toolset



MBSE Extension of GEMINI Tool



Provides CM of technical parameters for other simulation tools and reuse of architecture established through other documents, reviews, and design processes

Provides interface for control of system parameter values, retrieval of stored system performance data, and linkage to other system views and reports

Conclusion

Summary

- Over the last 5 years, our extensive work had demonstrated that the utilization of architecting methodologies and modeling & simulation tools reduces the lifecycle for the formulation and design of complex communication systems and networks, with greater confidence and lower costs
- Our integrated approach to these practices aids in the comparison of alternative architectures, facilitates the derivation and analysis of system requirements, and helps to predict design feasibility and compliance.
- Our plan to integrate our GEMINI toolset with MBSE databases will reduce the amount of required toolset maintenance and configuration management costs

Questions?